Modeling In-Vehicle Reaches Perturbed by Ride Motion

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ABSTRACT

Aside the capital investment and without the ability to otherwise simulate, motion capture is the preferred method by which to model human movements in a digital environment. However, these capture sessions are almost universally conducted in stationary environments. While this may be adequate for modeling many industrial applications of digital modeling, many other jobs require operators to perform tasks while being exposed to a moving environment (e.g. postal drivers, flight attendants, and numerous military and transportation operations). The Ride Motion Simulator (RMS) at the US Army – Tank Automotive and armaments Command (TACOM) simulated single-axis sinusoids and 6DOF ride motion, in which twelve participants were asked to perform extended reaches to eight push-button targets. In order to better ascertain the effects of dynamic ride motion on in-vehicle reaching tasks, we used a twelve-camera VICON optical motion capture system to record and UGS PLM Solutions' *JACK* to analyze the associated kinematic and kinetic motions. Recent studies have presented methodologies and results from motion capture studies of human reach performance under ride motion perturbation (Rider et al. 2003a, 2003b). Additional studies are underway to augment the development of regression models predicting movement time and the required target size based on task and ride conditions. Results of the reach data reveal the critical nature of the design and layout of controls, with respect to torso-included motions, ellipsoid-shaped buttons, and an increase in movement time required to successfully complete an in-vehicle task under ride motion.

INTRODUCTION

The human body is an extraordinary dynamic system, inherently capable of performing an infinite number of tasks, in an infinite number of ways. Despite this complexity, increasing effort is being placed on developing the ability to simulate and even predict human movement, based on given task and environmental conditions. Commercial digital human modeling (DHM) software has provided essential functionality for manipulating digital humans, or avatars, for simulation purposes. Although relatively adequate representations can be made, the validity of postures and motions is essential to any movement analysis (Chaffin 2001). Much work has been done to simulate and predict accurate human representations, particularly in the performance of seated and standing tasks (Faraway 2000, 2001, 2003).

Unfortunately typical DHM applications involve stationary environments, drastically different from those often experienced in military, transportation, and construction industries for example. Workers in these fields are often exposed to varying levels of whole-body vibration (WBV), which regularly cause nontrivial performance degradation. Many dynamic human models have been developed and validated for specific uses, such as crash and seat testing. Some human biodynamic response models utilize transfer functions of transmissibility and inertial properties of the human (Matsumoto and Griffin 2001). Many of these "mechanistic" models are developed through matching inputs and outputs to some degree, and have no predictive power (Griffin 2001). They are also generally deterministic and lack the essential understanding of the biodynamic response of the human body.

Another type of modeling involves the prediction and prevention of dynamic effects. These "effects" models typically only have some, if any, understanding of the mechanisms involved, which can negate much of their usefulness. A more critical flaw when modeling human movement is that neither of these models incorporate the motor control planning and execution aspects inherent to human movement, particularly the ability to make on-line corrections to motions as necessary to successfully complete the desired task.

The execution of a specific movement is planned in advance, based on the memory of previously executed motions (Park et al. 2002). These memories are stored as motor programs to be executed at a later time (Schmidt 1987). Each individual has different

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14. ABSTRACT

Aside the capital investment and without the ability to otherwise simulate, motion capture is the preferred method by which to model human movements in a digital environment. However, these capture sessions are almost universally conducted in stationary environments. While this may be adequate for modeling many industrial applications of digital modeling, many other jobs require operators to perform tasks while being exposed to a moving environment (e.g. postal drivers, flight attendants, and numerous military and transportation operations). The Ride Motion Simulator (RMS) at the US Army ? Tank Automotive and armaments Command (TACOM) simulated single-axis sinusoids and 6DOF ride motion, in which twelve participants were asked to perform extended reaches to eight push-button targets. In order to better ascertain the effects of dynamic ride motion on in-vehicle reaching tasks, we used a twelve-camera VICON optical motion capture system to record and UGS PLM Solutions? JACK to analyze the associated kinematic and kinetic motions. Recent studies have presented methodologies and results from motion capture studies of human reach performance under ride motion perturbation (Rider et al. 2003a, 2003b). Additional studies are underway to augment the development of regression models predicting movement time and the required target size based on task and ride conditions. Results of the reach data reveal the critical nature of the design and layout of controls, with respect to torso-included motions, ellipsoid-shaped buttons, and an increase in movement time required to successfully complete an in-vehicle task under ride motion.

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experiences of previous attempts at completing similar tasks and thus the high-level decision of which motor program to employ will and should be different for each individual. Equally as important is the coordinated effort of the central nervous system (CNS) to complete a task in the presence of perturbations. An understanding of this decision-making process is essential in determining how the motor program is adapted on-line due to the ride motion perturbation.

In the present study, we investigated the capabilities, and inherent limitations, of participants' reach performance when subjected to six degree-of-freedom (6DOF) ride motion. Using motion capture and DHM software, we analyzed the kinematics and trajectories to develop an understanding of how the CNS develops, executes, and alters motor programs under dynamic ride motion. Movement time and the fingertip variability at the destination of the reach (i.e. effective target width) were the principal performance metrics used.

The intended goal of this ongoing research is the development of an intelligent effects model, incorporating the mechanistic response of the human body to whole-body vibration and the CNS' ability to plan, execute, and alter reaching movements under ride motion perturbation.

MATERIALS AND METHODS

The Ride Motion Simulator (RMS) Laboratory at the US Army – Tank Automotive and armaments Command (TACOM) was used to simulate 6DOF random ride motion in each of the three primary axes: vertical, lateral, and longitudinal. Under these ride conditions as well as a stationary condition, participants performed push-button reaching tasks to eight (8) targets located in the right-hand reach envelope. Twelve participants volunteered for this study, six men and six women.

Table 1. Relevant characteristics of participants.

#	Gender	Age	Stature (cm)	Rt. Arm Length	Weight (kg)
S1	Male	45	178	81.2	69.1
S2	Female	22	160	67.7	62.7
S3	Male	28	185	88.5	79.5
S4	Male	23	173	71.5	65.5
S5	Female	25	180	78.1	76.4
S6	Male	27	173	74.6	73.6
S7	Male	22	170	71.2	69.5
S8	Female	24	168	69.4	64.5
S9	Male	26	180	79.4	97.7
S10	Female	30	170	68.9	60.0
S11	Female	32	168	67.7	66.4
S12	Female	36	170	75.3	53.6

Road profiles were recorded from a HMMWV (Hummer) traveling at 56 KPH on the Perryman 3 test track at the

US Army's Aberdeen Proving Grounds. Drive files were then generated for simulation in the RMS and the response of the cab was successfully validated against the original data recorded from the Hummer. These files were inputted to the RMS during the reach experiment at three different amplitudes, 40%, 70% and 100% of the original power. The road profiles were divided into two-Hz frequency bands, centered on the following frequencies: 2 Hz, 4 Hz, 6 Hz, and 8 Hz. A stationary cab condition (0 Hz) completes the low frequency analysis about an approximate torso resonance of 4 Hz.

In a related experiment, from which partial results have been previously published (Rider et al. 2003a, 2003b), sinusoidal inputs of the same frequencies inclusive between zero and 8 Hz will be used to further validate developed dynamic models. Performance effects will be determined for each individual frequency and the effects resulting from each will be assumed to be additive towards predicting the total response.

A twelve-camera VICON 524 motion capture system, sampling at 60 Hz was used to record the movement of twenty-nine (29) reflective markers placed on key anatomical landmarks of the participant. The cameras were positioned around and above the RMS cab as in Figure 1, resolving much of the potential occlusion. The VICON system was also used to record analog data from the eight target pushbuttons and a HOME switch; the location of the right hand on the steering wheel at the beginning of every reach. The VICON system and associated software were used to process the files into *.c3d motion files and *.csv files combining the marker trajectories and the analog data.

Figure 1. RMS setup, participant in Home position.

Four of the eight targets were reachable from a normal seated posture, without having to bend the torso. These targets are depicted in Figure 2. For later reference, these targets are numbered visually clockwise from the upward reach: 1, 3, 5, and 7.
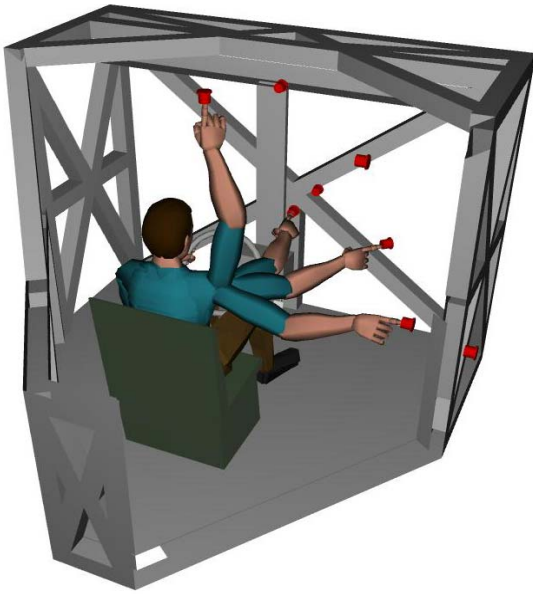
Figure 2. Depiction of reaches to targets 1, 3, 5, and 7, which do not require torso flexion (visually clockwise from upward reach)

Reaches to the remaining four targets are depicted in Figure 3 and all required a moderate bend of the torso, which was calculated from the VICON data. These target locations are also referenced later, numbered 2, 4, 6, and 8 respectively.
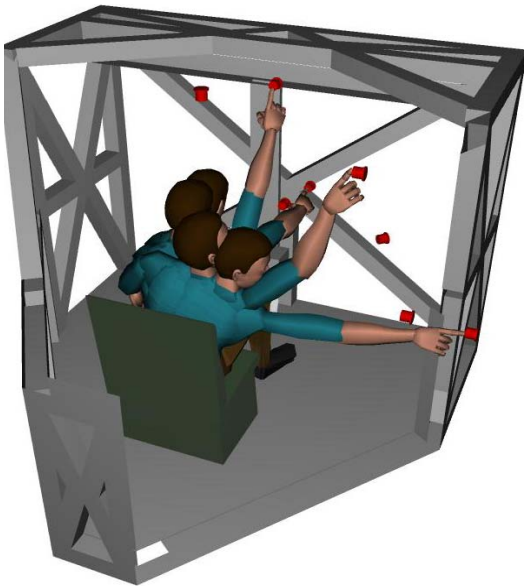

Figure 3. Depiction of reaches to targets 2, 4, 6, and 8, which require torso flexion (visually clockwise from upward reach)

A training exercise was given to the participants to familiarize them with the target locations until reaction and movement times of reaches were consistent reaches were provided in response to voice commands. The first experiment of this study was to measure participants' reach performance through two sets of reaches performed while seated in the stationary cab: self-paced and ballistic.

Repeated self-paced reaches were performed, from which a regression model was fitted and considered to be the "desired trajectory" that the participant was attempting to follow. Similar to the "linearity index" (Atkeson and Hollerbach 1985), a "trajectory index" was used to determine the extent to which ride motion affected the desired reach. This trajectory index is the ratio between the largest deviation of the actual movement from the desired trajectory and the linear distance from the start to the end of the reach. This index also serves as a measure of reach difficulty; higher indices indicate more difficult reaches.

[NOTE to reviewers: another related index is being developed to incorporate the movement time component into the above mentioned "trajectory index"]

Ballistic reaches were also performed providing data regarding the minimum time the participant could successfully complete the reaching task. Trajectories of these reaches were compared to ascertain differences in the selection of motor programs and their execution.

PERFORMANCE METRICS

Movement time was used as a primary performance metric, measured from the moment that the hand departed the steering wheel until the fingertip contacted the push button. Unsuccessful reaches were repeated, randomly reinserted in the experimental block. Trajectories of joints (e.g. wrist, elbow, shoulder, and waist) and body segments (e.g. forearm, upper arm, and torso) were also compared to identify movement strategies observed through the onset and duration of their motion. References to movement times are normalized for reach distance unless otherwise stated.

Effective target width was also measured from the variation of fingertip in the plane orthogonal to its motion. Hence the fingertip variability during a reach to an overhead target would be measured in both horizontal axes. The axes of the target ellipses were predicted using a type of principal component analysis providing 95% confidence intervals (Sokal and Rohlf 1981)

RESULTS

[NOTE to reviewers: ongoing data analysis will provide more explicit results supporting conclusions. Trajectory indices and 95% C.I. ellipses are forthcoming.]

Individual and average reach trajectories determined from the self-paced reaches were mostly linear as many literature sources assume with noticeable discrepancies at the beginning at the ending of the reaches. Figure 4 shows an example of one participant's reaches to the eight target locations. Recall that the origin of the reach trajectories shown is the right fingertip on the steering wheel and not the subject. Counterclockwise from the top-left are the following views (cab-relative direction): from top (forward up), from back (top up), from right side

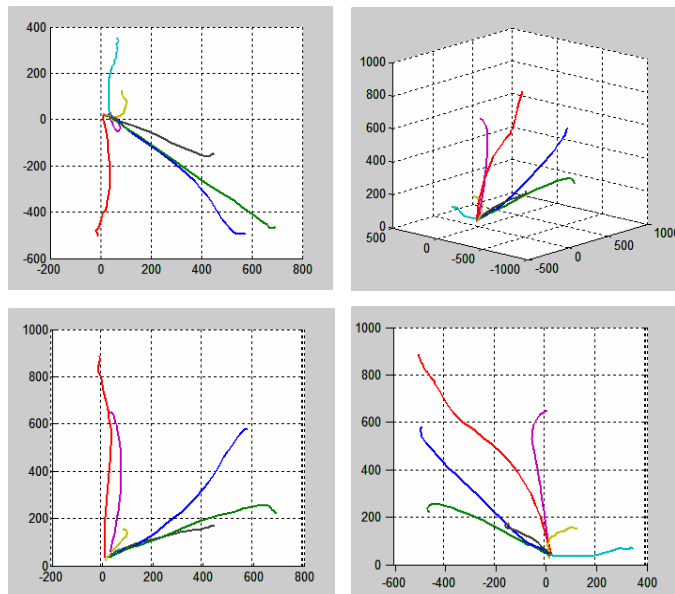(top up), and oblique from back-left. There is a nonlinearity in

Figure 4. Graphical views of one participant's reach trajectories to eight target locations.

The phase-plane diagram in Figure 5 provides some timing insight into the above graphs. A roughly proportional relationship between movement amplitude and peak velocity is apparent.

Phase-plane diagram of fingertip position vs. speed
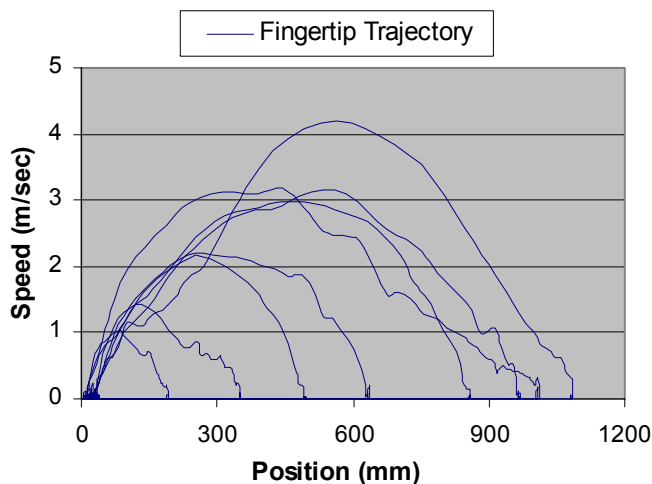

Figure 5. Phase-plane diagram of one participant's reaches to each of the eight targets.

Reach difficulty was not directly measured, but a positive correlation is assumed between normalized movement time and the difficulty of the reach. As such, there is a consistent increase in normalized movement time when compared to reach distance. However there is an additional discontinuity in movement time for reaches that include forward or lateral flexion of the torso. Averaging across all reaches, those that included the torso were <u>7.3%</u> longer than those without significant torso motion.

Additionally vertical reaches were nearly 5% longer than reaches in either lateral or longitudinal directions, presumably due to the effect of gravity.

[Principal Component Analysis of the effective target size is ongoing, as is the evaluation of trajectory modification through the trajectory index.

Longer movement times and higher trajectory indices are due to the frequency and amplitude of the ride motion

Anthropometric differences will be analyzed as well.]

CONCLUSION

The observed trajectories appear to have three oft-masked phases: initial movement, travel, and final adjustment. The phases are not always apparent, but may be a function of the timing of joint movements, as many studies have suggested. Analysis of these data does not seem to provide strong support to either side of the ongoing debate over whether the CNS plans movement with the end-effector or joints as the frame of reference. There are apparent indications in the data where both strategies may be utilized, and certainly it is reasonable to conceive that different situations may be solved differently by the CNS.

We suggest that the motor program of the desired trajectory may be joint-based, but that online changes to the trajectory to satisfy the end goal are made with an end-effector-based strategy. This solution satisfies observations of trajectories under higher amplitudes of ride motion.

Changes made to the arm and fingertip trajectories under ride motion are particularly noticeable for lateral reaches, where the fingertip tends to travel closer to the body enroute to the target. Thus the reduced moments and resulting torques about the shoulder makes the arm more maneuverable. Likewise when torso flexion is required under rough ride motion, the onset of torso motion is delayed to provide a more controllable torso-arm linkage.

The success of a reach and its movement time are also believed to be partially dependent on the perceived difficulty of the task. Nonlinearities in movement time may arise when targets are perceived as easily reached when they are not and thus produce an increased number of "misses". The cost of missing the target must be included in the determination of target size. The 95% confidence ellipses provide additional information for the spacing between buttons and the layout of buttons and controls. Perhaps control panels could be designed with more diagonally-oriented buttons providing more area to miss in the principal component directions.

The "effective target width" and an actual design guideline may then vary due to the perceived difficulty of accurately pressing a button of a given size. Further

study must be done to determine and validate extrapolations for predictions in dynamic environments.

There are of course additional factors contributing to the variability in movement time and accuracy, such as anthropometry, coordination, and motivation. Thus generating design guidelines remains a difficult undertaking; however gaining sufficient understanding for the prediction and simulation of human movement in dynamic environments is plausible.

Future analysis and validation phases of this research will incorporate the transfer functions of the transmitted vibration to compare the expected dynamic response of the body to the measured response. With this, the "mechanistic-effects" model begins to develop.

This study provided excellent data for between-subject variation, although it is much more useful for explanatory means, rather than predictive. Within-subject variation must be more definitely addressed and measured to provide the needed predictive power to develop a dynamic model of reach capability. However, ideal design recommendations may have to include a priori knowledge of the anthropometry and coordination of the user.

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REFERENCES

1. Atkeson, C.G., Hollerbach, J.M. (1985) "Kinematic features of unrestrained vertical arm movements", *J. Neuroscience, 5*: 2318-2330.
2. Chaffin, D.B. (2001) "Digital human modeling for vehicle and workplace design," Society of Automotive Engineers: Warrendale, PA.
3. Faraway, J.J. (2003) "Data-based Motion Prediction," SAE Digital Human Modeling Conference, Montréal, Canada, 2003-01-2229.
4. Faraway, J.J., Hu, J. (2001) "Modeling variability in reaching motions," SAE Digital Human Modeling Conference, Arlington, VA, 2001-01-2094.
5. Faraway, J.J. (2000) "Modeling reach motions using functional regression analysis," SAE Technical Paper 2000-01-2175, Warrendale, PA.
6. Gordon, J., Ghez, C. (1987) "Trajectory control in targeted force impulses. III. Compensatory adjustments for initial errors," *Experimental Brain Research, 67*: 253-269.
7. Griffin, M.J. (2001) "The validation of biodynamic models," *Clinical J. Biomechanics, 16*(Supplement No. 1): S81-S92.
8. Griffin, M.J. (1990) Handbook of human vibration. London: Academic Press, ISBN: 0-12-303040-4.
9. Matsumoto, Y., Griffin M.J. (2001) "Modelling the dynamic mechanisms associated with the principal resonance of the seated human body," *Clinical J. Biomechanics, 16*(Supplement No. 1): S31-S44.
10. Park, W.; Chaffin, D.B.; Martin, B.J. (2002) "Memory-based Human Motion Simulation," SAE Digital Human Modeling Conference, Munich, Germany.
11. Rider, K.A., Chaffin, D.B., Nebel, K.J., Mikol, K.J., Reed, M.P. (2003) "A Pilot Study of the Effects of Vertical Ride Motion on Reach Kinematics," SAE Technical Paper, 2003-01-0589, Warrendale, PA.
12. Rider, K.A., Park, W., Prohaska, M.P. (2003) "Effects of Vertical Land-Vehicle Ride Motion on Human Reach Performance and Perceived Task Difficulty," 47th Annual Meeting of the Human Factors and Ergonomics Society, Denver, CO.
13. Schmidt, R.A. (1987) Motor control and learning: A behavioral emphasis, 2nd ed. Human Kinetics: Champaign, IL.
14. Sokal, R.R., Rohlf, F.J. (1981) Biometry, Freeman: San Francisco, CA.

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